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DESCRIPTION

Loop Thermosyphon, Stirling Refrigerator and Cooling Apparatus

Technical Field

The present invention relates generally to loop thermosyphons, Stirling refrigerators having the loop thermosyphon mounted, and cooling apparatuses equipped with a Stirling refrigerating machine.

Background Art

Conventionally, heat radiation systems employing heat sinks, heat pipes, thermosyphons and the like have been known as heat radiation systems radiating heat generated from heat sources. For a heat radiation system with a heat sink attached to a heat source, the heat sink has a significant distribution in temperature. As such, the remoter it is from the heat source, the less it contributes to heat radiation. It thus has its limit in improving heat radiation performance. In contrast, heat radiation systems employing a heat pipe, a thermosyphon or the like employ a working fluid to transfer heat generated at a heat source. As such, they have a significantly higher ability to transfer heat than a heat sink and can thus maintain high heat radiation performance.

A heat pipe is a capillarity driven heat transfer device circulating a working fluid through a capillary action of a wick arranged in a closed circuit. By contrast, a thermosyphon is a gravity driven heat transfer device utilizing a difference in density of a working fluid that is caused as the working fluid evaporates and condenses. Note that a loop thermosyphon is a thermosyphon configured to circulate a working fluid in a closed circuit formed in a loop.

Initially as a first conventional example a typical loop thermosyphon will be described. Figs. 17A and 17B schematically show the first conventional example of loop thermosyphon in structure, as seen in front and side views, respectively.

As shown in the figures, a loop thermosyphon 100I includes an evaporator 110

depriving a heat source of heat and a condenser 130I externally discharging heat. Evaporator 110 and condenser 130I are connected by a feed pipe 120 and a return pipe 140, and evaporator 110, feed pipe 120, condenser 130I and return pipe 140 together form a closed circuit. Note that condenser 130I is disposed at a position higher than evaporator 110.

In evaporator 110 a working fluid deprives the heat source of heat and thus evaporates, and ascends by a vapor pressure difference between evaporator 110 and condenser 130I against gravity through feed pipe 120 and enters condenser 130I. Condenser 130I cools and thus condenses the working fluid, which is in turn pulled by gravity, and thus descends through return pipe 140 and enters evaporator 110. Such convection of the working fluid involving a change in phase as described above allows the heat source to externally radiate heat.

Stirling refrigerators equipped with a loop thermosyphon thus configured are disclosed for example in Japanese Patent Laying-Open Nos. 2003-50073, 2001-33139 and 2003-302117 (Patent Documents 1, 2 and 3).

As a second conventional example a cooling apparatus equipped with a conventional Stirling refrigerating machine described in Patent Document 3 will be described more specifically. Fig. 20 is a side view schematically showing a configuration of the cooling apparatus in the second conventional example. The figure shows a cooling apparatus 50 including a heat transfer cycle 5 associated with a cold portion and extracting cold generated at Stirling refrigerating machine 1, and a heat transfer cycle 4 associated with a heated portion and externally radiating hot. Stirling refrigerating machine 1 includes a cold portion 3 absorbing heat to generate cold as an internally sealed working medium (e.g., helium) expands, and a heated portion 2 generating hot as the working medium expands.

Heat transfer cycle 5 associated with the cold portion is generally a circulation circuit including a condenser 12 associated with the cold portion and attached around and in contact with cold portion 3, and an evaporator 15 associated with the cold

portion and connected to condenser 12 via a condensate coolant pipe 13 and a vapor coolant pipe 14. This circuit has carbon dioxide, hydrocarbon or the like sealed therein as a coolant to form a thermosyphon therein. Evaporator 15 has a plurality of fins 16 each in the form of a flat plate to exchange heat over an increased area. Furthermore, to allow the coolant's evaporation and condensation and resultant natural circulation to be utilized, evaporator 15 is arranged to be lower than condenser 12. Below condenser 15 is arranged a drain plate 17 to reserve drainage condensed on and dropping from a surface of evaporator 15.

Heat transfer cycle 4 associated with the heated portion is a thermosyphon employing water, hydrocarbon or a similar natural coolant, and generally a circulation circuit including an evaporator 6 associated with the heated portion and attached to Stirling refrigerating machine 1 at heated portion 2, a condenser 8 associated with the heated portion and arranged to be higher than evaporator 6 to condense the natural coolant, and a vapor coolant pipe 7 and a condensate coolant pipe 11 connecting evaporator 6 and condenser 8 together to circulate the coolant. The circuit has water (including an aqueous solution), hydrocarbon or a similar natural coolant sealed therein as the coolant. The use of water (including the aqueous solution), hydrocarbon or the like as a coolant can eliminate negative effect on environment, human body and the like. Note that to allow the coolant's evaporation and condensation and resultant natural circulation to be smoothly provided, condensate coolant pipe 11 is connected to evaporator 6 at a topmost end. Condenser 8 has a plurality of fins 18 each in the form of a flat plate attached thereto to exchange heat over an increased area and behind condenser 8 is provided a pair of heat radiating fans 19 operated to externally discharge heat.

Fig. 21 is a perspective view specifically showing a structure of the heat transfer cycle associated with the heated portion in the cooling apparatus described as the second conventional example. With reference to the figure, heat transfer cycle 4 will further more specifically be described in structure. Evaporator 6 as a whole forms a

ring, which is adapted to have a structure formed of two semi-rings 6A and 6B joined together along the ring's diameter to help to attach evaporator 6 to Stirling refrigerating machine 1 at heated portion 2. Each semi-ring 6A, 6B is an arc having opposite ends or surfaces closed. Semi-rings 6A and 6B are arranged to surround heated portion 2 and joined together vertically thereabove and therebelow, and have their respective lower ends connected by a U-letter communication pipe 6C for communication. Semi-rings 6A and 6B have their internal coolant's condensate communicated through connection pipe 6C and thus mixed together.

Vapor coolant pipe 7 is formed of two vertical pipes 7A and 7B connected to semi-rings 6A and 6B, respectively, and a lateral pipe 7C (also referred to as a header pipe) connected to vertical pipes 7A and 7B. Vertical pipes 7A and 7B are connected to semi-rings 6A and 6B at their respective outer circumferential, upper ends, respectively, and lateral pipe 7C at a bottommost portion vertically. Lateral pipe 7C has longitudinally opposite end surfaces closed and is arranged in a direction orthogonal to an axis of Stirling refrigerating machine 1 and horizontally.

Condensate coolant pipe 11 is similar in structure to pipe 7, although to form a thermosyphon, vapor coolant pipe 7 has lateral pipe 7C arranged at a position higher than a lateral pipe 11C of condensate coolant pipe 11, and to efficiently operate the thermosyphon, the vertical and lateral pipes are both relatively larger in diameter for vapor coolant pipe 7 than condensate coolant pipe 11.

Condenser 8 is formed of six serpentine tubes 8A-8F arranged in parallel in the longitudinal direction of lateral pipes 7C and 11C, or horizontally. Serpentine tubes 8A-8F each have one end connected to lateral pipe 7C and the other end to lateral pipe 11C and together connect lateral pipes 7C and 11C together equally in their longitudinal direction. Furthermore, the plurality of fins 18 are arranged at a linear portion of serpentine tubes 8A-8F in parallel and thermally coupled therewith.

Heat transfer cycle 4 operates as described hereinafter. Heated portion 2 generates heat which is in turn transferred from around heated portion 2 to evaporator 6

and evaporates the coolant in semi-rings 6A and 6B. The coolant evaporated in semi-ring 6A and that evaporated in semi-ring 6B ascend through the vapor coolant pipe 7 vertical pipes 7A and 7B, respectively, and are joined in lateral pipe 7C and then branched to flow into serpentine tubes 8A-8F. Thus the coolant's vapor passes through condenser 8 arranged at a position higher than evaporator 6 and exchanges heat via fin 18 with the surrounding ambient and thus becomes a condensate.

The condensate (or that having gas mixed together) conflows in condensate coolant pipe 11 at lateral pipe 11C and furthermore branches to vertical pipes 11A and 11B and flows downward to return to evaporator 6 and is again evaporated by heat of heated portion 2. By thus utilizing latent heat in the coolant's evaporation and condensation a significantly larger amount of heat is transferred than by utilizing exchange heat through sensible heat. This allows heat to be exchanged significantly effectively. Furthermore in the present invention, as described above, a difference in level between condenser 8 and evaporator 6 vertically arranged and a difference in specific gravity between gas and liquid provide a difference in pressure providing a driving force to circulate the coolant. This can eliminate the necessity of employing a pump or a similar external force to circulate the coolant and thus save energy.

Patent Document 1: Japanese Patent Laying-Open No. 2003-050073

Patent Document 2: Japanese Patent Laying-Open No. 2001-033139

Patent Document 3: Japanese Patent Laying-Open No. 2003-302117

Disclosure of the Invention

Problems to be Solved by the Invention

The above described, first conventional example's loop thermosyphon 100I often has condenser 130I with a variety of pipes and radiating fins combined together in an assembly and thus unitized and thus fabricated. More specifically, it is fabricated as an assembly formed of a header pipe 131 associated with a feed pipe and branching a working fluid introduced through a feed pipe 120, a header pipe 132 associated with a return pipe and allowing the branched working fluid to rejoin, a plurality of aligned pipes

133 extending in the same direction and connecting header pipes 131 and 132 together (see Fig. 18), and a radiating fin (not shown) assembled in contact with the plurality of aligned pipes 133.

Typically, as shown in Fig. 18, the plurality of aligned pipes 133 each have linear portions 134a-134d extending linearly in one direction and arranged in parallel in layers to form a plurality of vertically arranged stages (in Fig. 18, four stages), and curved portions 135a-135c connecting linear portions 134a-134d together. More specifically, each aligned pipe 133 is formed to be a serpentine tube as shown in Fig. 18. The plurality of linear portions 134a-134d are arranged in parallel layers mainly in order to facilitate fabrication and also ensures a maximum heat transfer area with a smaller space.

Condenser 130I implemented by the assembly thus configured is arranged in equipment (e.g., a Stirling refrigerator) having loop thermosyphon 100I mounted, at a casing 300 above a bottom surface 301, as shown in Fig. 17. Note that condenser 130I implemented by the assembly is arranged parallel to bottom surface 301.

When the equipment having loop thermosyphon 100I mounted has casing 300 with bottom surface 301 parallel to a surface on which it is disposed, or a floor surface 401, as shown in Fig. 18, condenser 130I has aligned pipe 133 with linear portions 134a-134d also parallel to floor surface 401. In that case, the working fluid condensed and thus liquefied in condenser 130I at aligned pipe 133 smoothly flows through aligned pipe 133 and is delivered through header pipe 132 and return pipe 140 to evaporator 110. Note that in the figure the working fluid flows in a direction indicated by an arrow 500.

If the equipment is disposed such that the casing has the bottom surface parallel to the floor surface, it does not cause a particular problem. If the casing has the bottom surface inclined relative to a horizontal floor surface or a floor surface itself is inclined and the casing is arranged parallel to the inclined floor surface, however, the loop thermosyphon will also be inclined relative to horizon and the working fluid's flow can be significantly affected thereby.

For example, if the equipment has casing 300 inclined relative to a horizontal floor surface 401 by an angle α_0, as shown in Fig. 19, then condenser 130I, having aligned pipe 133 with linear portions 134a-134d also parallel to the casing 300 bottom surface 301, will be inclined relative to the horizontal plane by angle α_0. Note that the shown condition shows that the equipment's casing 300 inclined and thus arranged so that the bottommost stage or linear portion 134d has an end adjacent to curved portion 135c lower in level than that adjacent to header pipe 132 associated with the return pipe.

If in that condition condenser 130I is arranged, the working fluid condensed and thus liquefied in condenser 130I at the bottommost stage or linear portion 134d is pulled by gravity and thus flows back and will stay in the bottommost stage or linear portion 134d closer to curved portion 135c. The condensed working fluid 502 will not flow into header pipe 132 associated with the return pipe, and as the equipment operates, working fluid 502 is gradually accumulated and finally will have a level 503 raised to close aligned pipe 133.

In such condition unless aligned pipe 133 has a considerably increased pressure at a portion closer to header pipe 131 associated with the feed pipe the working fluid will be prevented from flowing. The working fluid circulates in an unexpected operation, and the heat generated at the heat source cannot be radiated sufficiently. As a result, the loop thermosyphon operates defectively, and in the worst case, the main body of the equipment having the loop thermosyphon mounted may fails.

Thus the first conventional example's loop thermosyphon can provide a defective operation depending on how it is arranged, and this has been a significantly serious issue to be addressed.

Furthermore the second conventional example's cooling apparatus 50 including Stirling refrigerating machine 1 is itself assembled independently and thereafter mounted in a refrigerator (not shown) and thus shipped as a product. Note that cooling apparatus 50 is incorporated so that when the refrigerator is disposed at a horizontal place lateral pipes 7C and 11C are horizontal.

However, if the second conventional example's cooling apparatus is thus incorporated, it cannot be expected that the user ensures that the refrigerator is disposed at a horizontal place, and in reality the refrigerator can be placed at a slanting place. In that case, as shown in Fig. 22, the entirety of the system will be inclined relative to the horizontal plane, and condensate coolant pipe 11 will have a condensate coolant 20 staying in a lateral pipe 11C at a portion lower than an upper end of a vertical pipe (in Fig. 22, 11B) lower in the direction of gravity. As a result, the coolant circulates in a reduced amount resulting in impaired heat radiation efficiency.

Accordingly the present invention contemplates a loop thermosyphon capable of preventing defective operation regardless of disposition, and a Stirling refrigerator equipped therewith.

The present invention also contemplates a cooling apparatus capable of reliably circulating a coolant in a heat transfer cycle associated with a heated portion of a Stirling refrigerating machine if the apparatus is inclined.

Means for Solving the Problems

A loop thermosyphon in a first aspect of the present invention is mounted at a casing of equipment having a heat source, and employs a working fluid enclosed in a closed circuit to externally radiate heat from the heat source. Note that a "loop thermosyphon mounted at a casing" as referred to herein includes a loop thermosyphon entirely accommodated in the casing and a loop thermosyphon partially accommodated in the casing and partially exposed. The closed circuit includes: an evaporator depriving the heat source of heat to evaporate the working fluid; a condenser condensing the working fluid evaporated at the evaporator; a feed pipe feeding to the condenser the working fluid evaporated at the evaporator; and a return pipe returning to the evaporator the working fluid condensed at the condenser. The condenser has a serpentine tube having a linear portion extending in one direction and forming a plurality of stages in layers, and a curved portion connecting such linear portions together, and the serpentine tube has a bottommost one of the linear portions inclined in a direction

allowing the bottommost linear portion to be closer to a bottom surface of the casing as the bottommost linear portion approaches the return pipe.

This can reduce the possibility that the working fluid condensed and liquefied will stay in the serpentine tube, and the loop thermosyphon's defective operation attributed to disposition can be reduced.

A loop thermosyphon in a second aspect of the present invention is mounted at a casing of equipment having a heat source, and employs a working fluid enclosed in a closed circuit to externally radiate heat from the heat source. The closed circuit includes: an evaporator depriving the heat source of heat to evaporate the working fluid; a condenser condensing the working fluid evaporated at the evaporator; a feed pipe feeding to the condenser the working fluid evaporated at the evaporator; and a return pipe returning to the evaporator the working fluid condensed at the condenser. The condenser is an assembly including a header pipe associated with the feed pipe, and connected to the feed pipe to branch the working fluid introduced thereinto, a header pipe associated with the return pipe, and connected to the return pipe and joining together the working fluid branched, and a plurality of aligned pipes extending in a same direction and connecting the header pipes together. The aligned pipes are each a serpentine tube having a linear portion extending in one direction and forming a plurality of stages in layers, and a curved portion connecting such linear portions together. The assembly or condenser is entirely inclined relative to a bottom surface of the casing such that of the linear portions, a bottommost linear portion is inclined in a direction allowing the bottommost linear portion to be closer to the bottom surface as the bottommost linear portion approaches the header pipe associated with the return pipe.

If the condenser is fabricated to be a unit such that the serpentine tube has the linear portion arranged in vertically parallel layers, the possibility that the working fluid condensed and liquefied will stay in the serpentine tube can nonetheless be reduced. The loop thermosyphon's defective operation attributed to disposition can thus be reduced.

Preferably in the loop thermosyphon in the second aspect of the present invention the condenser is arranged to incline relative to the bottom surface of the casing at an angle larger than 0° and at most 6°.

The condenser that is previously inclined to satisfy such condition can significantly prevent the loop thermosyphon's defective operation attributed to disposition.

Preferably in the loop thermosyphon in the second aspect of the present invention the header pipe associated with the return pipe extends in a second direction traversing the first direction, the return pipe is connected in a vicinity of one end of the header pipe associated with the return pipe and extending in the second direction, and the header pipe associated with the return pipe is inclined in a direction allowing the header pipe associated with the return pipe to be closer to the bottom surface of the casing as the header pipe associated with the return pipe extends toward the one end from the other end positionally opposite the one end.

This can reduce the possibility that the working fluid condensed and liquefied will stay in the header pipe associated with the return pipe. The loop thermosyphon's defective operation attributed to disposition can thus be reduced.

A loop thermosyphon in a third aspect of the present invention is mounted at a casing of equipment having a heat source, and employs a working fluid enclosed in a closed circuit to externally radiate heat from the heat source. The closed circuit includes: an evaporator depriving the heat source of heat to evaporate the working fluid; a condenser condensing the working fluid evaporated at the evaporator; a feed pipe feeding to the condenser the working fluid evaporated at the evaporator; and a return pipe returning to the evaporator the working fluid condensed at the condenser. The condenser is an assembly including a header pipe associated with the feed pipe, and connected to the feed pipe to branch the working fluid introduced thereinto, a header pipe associated with the return pipe, and connected to the return pipe and joining together the working fluid branched, and a plurality of aligned pipes extending in a same

direction and connecting the header pipes together. The header pipe associated with the return pipe extends in one direction. The return pipe is connected in a vicinity of one end of the header pipe associated with the return pipe and extending in the one direction. The header pipe associated with the return pipe is inclined in a direction allowing the header pipe associated with the return pipe to be closer to a bottom surface of the casing as the header pipe associated with the return pipe extends toward the one end from the other end positionally opposite the one end.

This can reduce the possibility that the working fluid condensed and liquefied will stay in the header pipe associated with the return pipe. The loop thermosyphon's defective operation attributed to disposition can thus be reduced.

A loop thermosyphon in a fourth aspect of the present invention is mounted at a casing of equipment having a heat source, and employs a working fluid enclosed in a closed circuit to externally radiate heat from the heat source. The closed circuit includes: an evaporator depriving the heat source of heat to evaporate the working fluid; a condenser condensing the working fluid evaporated at the evaporator; a feed pipe feeding to the condenser the working fluid evaporated at the evaporator; and a return pipe returning to the evaporator the working fluid condensed at the condenser. The condenser is an assembly including a header pipe associated with the feed pipe, and connected to the feed pipe to branch the working fluid introduced thereinto, a header pipe associated with the return pipe, and connected to the return pipe and joining together the working fluid branched, and a plurality of linear tubes arranged in parallel and connecting the header pipes together. The linear tubes are each inclined in a direction allowing each the linear tube to be closer to a bottom surface of the casing as each the linear tube approaches the header pipe associated with the return pipe.

If a condenser is employed that has a linear tube, rather than a serpentine tube, connecting together header pipes associated with feed and return pipes, respectively, the condenser will not have a working fluid convected in the pipe, and the loop thermosyphon's defective operation attributed to disposition can thus be reduced.

The present Stirling refrigerator is a Stirling refrigerator having a Stirling refrigerating machine mounted. The Stirling refrigerating machine includes any of the loop thermosyphons in the first to fourth aspects of the present invention and the loop thermosyphon has an evaporator configured to exchange heat with a heated portion of the Stirling refrigerating machine.

The Stirling refrigerator thus configured is not affected in performance by how a casing is disposed.

A cooling apparatus in a first aspect of the present invention has a heat transfer cycle associated with a cold portion and extracting cold generated by a Stirling refrigerating machine at the cold portion, and a heat transfer cycle associated with a heated portion and externally radiating hot generated by the Stirling refrigerating machine at the heated portion. The heat transfer cycle associated with the heated portion includes an evaporator associated with the heated portion and attached to the Stirling refrigerating machine at the heated portion and a condenser associated with the heated portion and arranged to be higher in level than the evaporator, with a vapor coolant pipe and a condensate coolant pipe connecting the evaporator and the condenser to form a coolant circulation circuit, and the condensate coolant pipe includes a lateral pipe having opposite ends closed and connected to the condenser and a pair of vertical pipes vertically connecting the evaporator and the lateral pipe together, the pair of vertical pipes having one and the other, upper ends connected to the lateral pipe at one and the other ends, respectively. If the cooling apparatus is inclined, the heat transfer cycle associated with the heated portion will not have the coolant's condensate staying in the lateral pipe.

In the cooling apparatus in the first aspect of the present invention the vertical pipe has an upper end with a lateral pipe connected thereto and a lower end with the evaporator associated with the heated portion connected thereto, however, the connections' ports do not necessarily, positionally match with each other as seen horizontally. Accordingly, the vertical pipe is provided with an inclined portion having

a downward gradient. In general, a refrigerator is installed at a place having an inclination within 5° for safety, and providing the vertical pipe with an inclined portion having a downward gradient of at least 5° with reference to the cooling apparatus placed in a horizontal position allows the downward gradient to be maintained if the cooling apparatus is inclined, and the coolant's condensate can be prevented from clogging.

A cooling apparatus in a second aspect of the present invention has a heat transfer cycle associated with a cold portion and extracting cold generated by a Stirling refrigerating machine at the cold portion, and a heat transfer cycle associated with a heated portion and externally radiating hot generated by the Stirling refrigerating machine at the heated portion. The heat transfer cycle associated with the heated portion includes an evaporator associated with the heated portion and attached to the Stirling refrigerating machine at the heated portion and a condenser associated with the heated portion and arranged to be higher in level than the evaporator, with a vapor coolant pipe and a condensate coolant pipe connecting the evaporator and the condenser to form a coolant circulation circuit. The condensate coolant pipe includes a lateral pipe having opposite ends closed and connected to the condenser and a pair of vertical pipes vertically connecting the evaporator and the lateral pipe together, and the vapor coolant pipe includes a lateral pipe having opposite ends closed and connected to the condenser and a pair of vertical pipes vertically connecting the evaporator and the lateral pipe together. The lateral pipe of the vapor coolant pipe is arranged to be higher in level than the lateral pipe of the condenser coolant pipe and a degassing charge pipe is attached to the vapor coolant pipe at the lateral pipe. The charge pipe attached at such a high position can prevent water from being sucked in vacuuming and also contribute to improved efficiency in vacuuming.

Effect of the Invention

The loop thermosyphon in the first to fourth aspects of the present invention can be prevented from defective operation regardless of disposition. Furthermore the Stirling refrigerator of the present invention can exhibit high performance regardless of

how the casing is disposed.

Furthermore in the cooling apparatus in the first and second aspects of the present invention as a Stirling refrigerating machine is driven a heated portion generates heat, which is transferred and externally radiated by a thermosyphon utilized in a heat transfer cycle associated with the heated portion and having a condensate coolant pipe passing the coolant's condensate naturally downward toward an evaporator associated with the heated portion, that is configured of a lateral pipe having opposite ends closed and disposed at an outlet of a condenser associated with the heated portion and a pair of vertical pipes vertically connecting together the lateral pipe and the evaporator associated with the heated portion, with each vertical pipe having an upper end connected to the lateral pipe at one and the other ends, respectively. If the cooling apparatus is inclined, the coolant's condensate does not stay in the lateral pipe of the heat transfer cycle associated with the heated portion. The cycle can thus circulate the coolant reliably.

Brief Description of the Drawings

Fig. 1 is a schematic, perspective view of a structure of the present loop thermosyphon in the first embodiment installed.

Fig. 2 schematically shows a configuration of a condenser of the Fig. 1 loop thermosyphon.

Figs. 3A and 3B schematically show how the condenser of the present loop thermosyphon in the first embodiment is installed, with the loop thermosyphon seen in front and side views, respectively.

Fig. 4 shows how a working fluid flows in the first embodiment when the condenser inclines relatives to a horizontal plane.

Fig. 5 shows how a working fluid flows in the first embodiment when the condenser inclines relatives to a horizontal plane.

Figs. 6A and 6B schematically show how the condenser of the present loop thermosyphon in a second embodiment is installed, with the loop thermosyphon seen in

front and side views, respectively.

Figs. 7A and 7B schematically show how the condenser of the present loop thermosyphon in a third embodiment is installed, with the loop thermosyphon seen in front and side views, respectively.

Fig. 8 schematically shows a configuration of a condenser of the present loop thermosyphon in a fourth embodiment.

Fig. 9 schematically shows how the present loop thermosyphon in the fourth embodiment is installed, as seen in a side view.

Figs. 10-13 schematically show configurations of the present loop thermosyphon in fifth to eighth embodiments, respectively.

Fig. 14 is a schematic cross section of a structure of the present Stirling refrigerator in a ninth embodiment.

Fig. 15 is a perspective view specifically showing a structure of a heat transfer cycle associated with a heated portion in a tenth embodiment of the present invention.

Figs. 16A and 16B are front and side views, respectively, of the heat transfer cycle associated with the heated portion in the tenth embodiment.

Figs. 17A and 17B schematically show a structure of a loop thermosyphon in a first conventional example, as seen in front and side views, respectively.

Fig. 18 schematically shows a structure of a condenser of the loop thermosyphon in the first conventional example, showing how a working fluid flows with the condenser disposed horizontally.

Fig. 19 shows how the working fluid flows with the Fig. 18 condenser inclined relative to a horizontal plane.

Fig. 20 is a side view schematically showing a structure of a cooling apparatus in a second conventional example.

Fig. 21 is a perspective view specifically showing a structure of a heat transfer cycle associated with a heated portion of the cooling apparatus of the second conventional example.

Fig. 22 is a front view of a main portion of the heat transfer cycle associated with the heated portion with the Fig. 20, second conventional example's cooling apparatus inclined.

Description of the Reference Signs

1: Stirling refrigerating machine, 2: heated portion, 3: cold portion, 4: heat transfer cycle associated with the heated portion, 5: heat transfer cycle associated with the cold portion, 6: evaporator associated with the heated portion, 6A, 6B: semi-ring, 7, 14: vapor coolant pipe, 7A, 7B: vertical pipe, 7C: lateral pipe, 8: condenser associated with the heated portion, 8A-8F: serpentine tube, 11, 13,: condensate coolant pipe, 11A, 11B: vertical pipe, 11Aa, 11Ba: inclined portion, 11C: lateral pipe, 12: condenser associated with the cold portion, 15: evaporator associated with the cold portion, 16, 18: fin in the form of a flat plate, 17: drain plate, 19: heat radiating fan, 20: coolant's condensate, 21: charge pipe, 50: cooling apparatus, 100, 100A-100I: loop thermosyphon, 110: evaporator, 112: inner circumferential surface, 120: feed pipe, 130, 130A-130I: condenser, 131: header pipe associated with feed pipe, 132: header pipe associated with return pipe, 133: aligned pipe, 134a-134e: linear portion, 135a-135d: curved portion, 136: radiating fin, 140: return pipe, 200: Stirling refrigerating machine, 202: pressure chamber, 204 heated portion, 206: cold portion, 250: supporting platform, 252: bottom plate, 254a-254c: support, 300: casing, 301: bottom surface, 401: floor surface, 500: direction in which working fluid flows, 502: liquefied working fluid, 503: surface of liquid, 1000: Stirling refrigerator, 1020: heat transfer system associated with cold portion, 1023: cold duct, 1024: duct, 1025: air blowing fan, 1026: fan associated with freezer section, 1027: fan associated with chiller section, 1028: freezer section. 1029: chiller section

Best Modes for Carrying Out the Invention

Hereinafter the present invention in embodiments will be described with reference to the drawings.

First Embodiment

Initially reference will be made to Fig. 1 to describe a loop thermosyphon in the present embodiment and a structure of a Stirling refrigerating machine installed with the loop thermosyphon attached thereto.

As shown in the figure, a Stirling refrigerating machine 200 is placed on a supporting platform 250 and supported by supports 254a, 254b provided on platform 250 at a bottom plate 252. Furthermore, a loop thermosyphon 100A is also placed on platform 250 and supported thereon by support 254a, 254c provided at a bottom plate 252. Stirling refrigerating machine 200 and loop thermosyphon 100A supported by platform 250 are disposed in a casing of prescribed equipment (e.g., a refrigerator). Note that platform 250 has bottom plate 252 parallel to a bottom surface of the casing of the equipment.

Stirling refrigerating machine 200 is structured and operates, as described hereinafter.

As shown in Fig. 1, Stirling refrigerating machine 200 includes a pressure chamber 202 provided therein with a cylinder having a piston and a displacer fitted and thus attached thereto. The cylinder is filled with helium or a similar working medium. The cylinder has an internal space sectioned by the piston and the displacer to provide a compression section and an expansion section. The compression section is surrounded by a heated portion 204 and the expansion section is surrounded by a cold portion 206.

The piston fitted in the cylinder is driven by a linear actuator to reciprocate in the cylinder. As the piston reciprocates and pressure accordingly varies, the displacer reciprocates in the cylinder with a constant phase difference from the piston's reciprocation. As the piston and the displacer reciprocate, an inverted Stirling cycle is implemented in the cylinder. Thus heated portion 204 surrounding the compression section rises in temperature and cold portion 206 surrounding the expansion section is cooled to cryogenic temperature.

Loop thermosyphon 100A has a structure and operates as described hereinafter.

As shown in Fig. 1, loop thermosyphon 100A includes an evaporator 110 and a

condenser 130A. Evaporator 110 is arranged in contact with heated portion 204 of Stirling refrigerating machine 200 to deprive heated portion 204 of heat to evaporate a working fluid introduced in evaporator 110. Condenser 130A is arranged at a position higher than evaporator 110 to condense the working fluid evaporated at evaporator 110. Evaporator 110 and condenser 130A are connected by a feed pipe 120 and a return pipe 140 to together form a closed circuit. Note that in loop thermosyphon 100A as shown in the figure a heat source, or heated portion 204, has a cylindrical geometry. Accordingly, evaporator 110 is formed of two arcuate components.

With reference to Figs. 1 and 2, condenser 130A is formed of a header pipe 131 associated with the feed pipe, a header pipe 132 associated with the return pipe, a plurality of aligned pipes 133 connecting headers 131 and 132, and a radiating fin 136 provided in contact with aligned pipes 133, assembled together to be a unit.

Header pipe 131 is a distributor connected to feed pipe 120 to branch the working fluid introduced. In contrast, header pipe 132 is connected to return pipe 140 to collect pipes to join branches of the working fluid together.

As shown in Fig. 2, aligned pipe 133 is each defined by linear portions 134a-134d (in four stages for condenser 130A in the present embodiment) linearly extending in a first direction (in the figure, a direction A), and curved portions 135a-135c connecting linear portions 134a-134d. Linear portions 134a-134d are arranged, one on another, vertically in parallel. Curved portions 135a-135c connect linear portions 134a-134d at their respective ends together. More specifically, condenser 130A is configured of aligned pipes 133 configured of laterally arranged serpentine tubes. The plurality of aligned pipes 133 at linear portions 134a-134d have a plurality of radiating fins 136 assembled thereto.

In evaporator 110 the working fluid deprives heated portion 204 of Stirling refrigerating machine 200 of heat and thus evaporates, and ascends by a vapor pressure difference between evaporator 110 and condenser 130A against gravity through feed pipe 120 and enters condenser 130A. Condenser 130A cools and thus condenses the

working fluid, which is in turn pulled by gravity, and thus descends through return pipe 140 and enters evaporator 110. Such convection of the working fluid involving a change in phase as described above allows heated portion 204 to externally radiate heat.

In the present embodiment loop thermosyphon 100A has condenser 130A arranged as described hereinafter.

As shown in Figs. 3A and 3B the present embodiment loop thermosyphon 100A has condenser 130A arranged to incline relative to bottom surface 301 of casing 300 of a refrigerator or similar equipment. More specifically, condenser 130A formed of an assembly is arranged to incline by an angle θ_1 so that an end of condenser 130A that is closer to header pipe 132 is closer to bottom surface 301 than that of condenser 130A farther away from header pipe 132 is

More specifically, condenser 130A is arranged to entirely incline by angle θ_1 to have aligned serpentine tube 133 with the bottommost linear portion 134d inclined to be closer to bottom surface 301 as the serpentine tube approaches header pipe 132. Condenser 130A is inclined relative to bottom surface 301 by angle θ_1 preferably of larger than 0° and at most 6°, more preferably approximately 3°. This can be done for example by adjusting support 254c of supporting platform 250 in height (see Fig. 1).

Thus arranging condenser 130A to incline relative to bottom surface 301 of casing 300 by angle θ_1 allows loop thermosyphon 100A to reliably operate regardless of how casing 300 is disposed, for the following reasons:

Initially, if casing 300 has bottom surface 301 parallel to a horizontal floor surface, then condenser 130A, previously arranged to incline relative to bottom surface 301 by angle θ_1, will also be arranged to incline relative to a horizontal plane by angle θ_1.

In condenser 130A aligned pipe 133 passes the working fluid, which is condensed and liquefied in the bottommost stage's linear portion 134d, and pulled by gravity to flow through the inclined linear portion 134d toward header pipe 132 and thus flow out of aligned pipes 133. Consequently, aligned pipe 133 will not have the working fluid staying therein. Thus the working fluid can smoothly flow and loop

thermosyphon 100A can reliably operate.

Hereinafter will be considered four cases with casing 300 having bottom surface 301 inclined relative to a horizontal floor surface.

In a first case, with reference to Fig. 3B, equipment has casing 300 inclined in a direction B. In that case, condenser 130A after installation will have an inclination of an angle larger than angle θ_1 relative to the horizontal plane.

As has been described above, the working fluid flowing in condenser 130A through aligned pipe 133 is condensed and liquefied mainly at the bottommost linear portion 134d, and pulled by gravity to flow through the inclined linear portion 134d toward header pipe 132 and flows out of aligned pipes 133. As such, aligned pipe 133 will not have the working fluid staying therein. As a result, the working fluid can smoothly flow and loop thermosyphon 100A can reliably operate.

If condenser 130A is arranged to incline by an angle larger than a prescribed angle, however, and the surrounding temperature or the like varies, aligned pipe 133 occasionally has the working fluid condensed and liquefied not only at the bottommost linear portion 134d but also linear portion 134c immediately overlying linear portion 134d. In that case, the condensed working fluid may stay in a vicinity of curved portion 135b adjacent to linear portion 134c and thus close aligned pipe 133. Such phenomenon occurs at a critical angle of approximately 6°, as confirmed by the inventor, although it slightly varies depending on how condenser 130A is designed in dimension or the like.

Typically, however, it is hardly conceivable that equipment is arranged on a floor surface having an inclination of 3° or larger and it is also hardly conceivable that the equipment's casing is arranged to incline relative to a horizontal floor surface by 3° or larger, and inclination or angle θ_1 set to be approximately 3° relative to bottom surface 301 of condenser 130A would substantially completely prevent such a situation as described above. Thus in most cases loop thermosyphon 100A can reliably operate.

In a second case, with reference to Fig. 3B, equipment has casing 300 inclined in

a direction C by an angle α_1, wherein $\alpha_1 < \theta_1$. With casing 300 thus inclined, condenser 130A after it is arranged will incline by an angle $\theta_1 - \alpha_1$ relative to a horizontal plane.

As has been described above, the working fluid flowing in condenser 130A through aligned pipe 133 is condensed and liquefied mainly at the bottommost linear portion 134d. However, condenser 130A is inclined relative to the horizontal plane by angle $\theta_1 - \alpha_1$. Accordingly the working fluid liquefied in the bottommost linear portion 134d flows through linear portion 134d toward header pipe 132 and flows out of aligned pipes 133. As such, aligned pipe 133 will not have the working fluid staying therein. As a result, the working fluid can smoothly flow and loop thermosyphon 100A can reliably operate.

In a third case, with reference to Fig. 3B, equipment has casing 300 inclined in a direction C by an angle α_2, wherein $\alpha_2 = \theta_1$. With casing 300 thus inclined, condenser 130A after it is disposed will be arranged horizontally.

As has been described above, the working fluid flowing in condenser 130A through aligned pipe 133 is condensed and liquefied mainly at the bottommost linear portion 134d. In that case, with the bottommost linear portion 134d horizontally disposed, the convection of the working fluid caused in aligned pipe 133 allows the liquefied working fluid to flow toward header pipe 132 and flow out of aligned pipe 133. As such, aligned pipe 133 will not have the working fluid staying therein. As a result, the working fluid can smoothly flow and loop thermosyphon 100A can reliably operate.

In a fourth case, with reference to Fig. 3B, equipment has casing 300 inclined in direction C by an angle α_3, wherein $\alpha_3 > \theta_1$. With casing 300 thus inclined, condenser 130A after it is arranged will incline by an angle $\alpha_3 - \theta_1$ relative to the horizontal plane.

As has been described above, the working fluid flowing in condenser 130A through aligned pipe 133 is condensed and liquefied mainly at the bottommost linear portion 134d. As shown in Fig. 5, the working fluid liquefied in linear portion 134d is pulled by gravity to flow through linear portion 134d to move away from header pipe

132. As a result, the liquefied working fluid 502 will stay in the bottommost linear portion 134d closer to curved portion 135c.

However, with condenser 130A previously arranged to incline relative to bottom surface 301 of casing 300, there is a smaller possibility that working fluid 502 staying in aligned pipe 133 has a level 503 closing aligned pipe 133 than when condenser 130A is arranged parallel to bottom surface 301 of casing 300. More specifically, as shown in Fig. 5, as long as aligned pipe 133 at a connection of the bottommost linear portion 134d and curved portion 135d has an upper portion (indicated in Fig. 5 by a point D) upper than a lower portion of the connection of the bottommost linear portion 134d and header pipe 132, working fluid 502 flowing back and thus staying will not close aligned pipe 133. As a result, the working fluid is not prevented from flowing and can flow smoothly.

It should be noted, however, that if condenser 130A is further inclined, i.e., if aligned pipe 133 at the connection of the bottommost linear portion 134d and curved portion 135d has an upper portion (indicated in Fig. 5 by point D) upper than a lower portion of the connection of the bottommost linear portion 134d and header pipe 132, then aligned pipe 133 will be closed by the liquefied working fluid, and the working fluid will be prevented from flowing. Typically, however, it is also hardly conceivable that equipment has a casing arranged with an inclination of 3° or larger relative to a horizontal floor surface, and inclination or angle θ_1 set to be approximately 3° relative to bottom surface 301 of condenser 130A would substantially completely prevent such a situation as described above. Thus in most cases loop thermosyphon 100A can reliably operate.

Note that while in the above description a casing is arranged to incline relative to a horizontal floor surface by way of example, the above also similarly applies if the casing is arranged parallel to an originally inclined floor surface.

Thus, as described in the present embodiment, previously arranging a condenser formed of an assembly to incline in a prescribed direction by a prescribed angle can

prevent a loop thermosyphon from defective operation attributed to disposition. The loop thermosyphon can reliably operate, and as a result the Stirling refrigerating machine can be protected against damage attributed to unexpected defective operation, and can also have a heated portion reliably cooled and hence operate significantly efficiently.

Second Embodiment

The present embodiment provides a loop thermosyphon 100B also utilized as a heat transfer system associated with a heated portion of a Stirling refrigerating machine, similarly as described in the first embodiment. Accordingly, the components similar to those of the first embodiment are shown in the figures with identical reference characters.

As shown in Figs. 6A and 6B, the present embodiment provides loop thermosyphon 100B with a condenser 130B similar to condenser 130A of loop thermosyphon 100A described in the first embodiment. More specifically, condenser 130B is unitized as an assembly formed of header pipe 131 associated with a feed pipe, header pipe 132 associated with a return pipe, the plurality of aligned pipes 133 connecting header pipes 131 and 132 together, and a radiating fin 136 provided in contact with aligned pipes 133.

Aligned pipe 133 has a linear portion extending in a first direction (indicated in the figure by an arrow A), and header pipe 132 associated with the return pipe extends in a second direction (indicated in the figure by an arrow E) traversing the first direction. Return pipe 140 is connected in a vicinity of one end of header pipe 132 extending in this one direction.

Condenser 130B is arranged to incline relative to bottom surface 301 of casing 300 of a refrigerator or similar equipment. More specifically, condenser 130B formed of an assembly is arranged to entirely incline by an angle θ_2 such that one end having return pipe 140 connected thereto is positioned to be closer than the other end corresponding to that opposite to one end.

More specifically, condenser 130B is arranged to entirely incline by angle θ_2 such that condenser 130A has header pipe 132 inclined in a direction allowing header

pipe 132 to have a smaller distance to bottom surface 301 for one end having return pipe 140 connected thereto than the other end located opposite to one end. Note that relative to bottom surface 301 condenser 130B is not particularly limited in inclination or angle θ_2, although it is preferably several degrees to an angle between 10 degrees and 20 degrees. Such inclination can be done for example by adjusting in geometry an upper and of support 254c of supporting platform 250 (see Fig. 1).

Thus by arranging condenser 130B to incline relative to bottom surface 301 of casing 300 by angle θ_2 and connecting return pipe 140 to header pipe 132 at an end closer to bottom surface 301, allows loop thermosyphon 100B to reliably operate regardless of how casing 300 is disposed, for the following reason:

The working fluid condensed and liquefied in the plurality of aligned pipes 133 flows through each aligned pipe 133 into header pipe 132 and thus joins to flow together, and further flows through return pipe 140 into evaporator 110.

If header pipe 132 is arranged parallel to bottom surface 301, header pipe 132 is not necessarily arranged horizontally, depending on how casing 300 is arranged relative to a floor surface, how the floor surface inclines, and the like. Accordingly, as shown in Fig. 17, a conventional loop thermosyphon has return pipe 140 connected to header pipe 132 at a center to provide a minimum distance to each aligned pipe 133 to allow the working fluid to smoothly flow.

If such arrangement is adopted, however, and header pipe 132 is arranged to incline, the working fluid is more, significantly prevented from flowing in header pipe 132 at a location lower than the portion connecting header pipe 132 and return pipe 140 together than at a location higher than that portion. Consequently in the plurality of aligned pipes 133 the working fluid experiences different flow resistances and the loop thermosyphon cannot operate efficiently.

In the present embodiment loop thermosyphon 100B has header pipe 132 arranged to previously incline relative to bottom surface 301 of casing 300 of equipment and has return pipe 140 connected to header pipe 132 at an end closer to bottom surface

301 to allow the working fluid to smoothly flow. As a result the loop thermosyphon can be prevented from defective operation attributed to disposition and thus reliably operate.

Third Embodiment

The present embodiment provides a loop thermosyphon 100C also utilized as a heat transfer system associated with a heated portion of a Stirling refrigerating machine, similarly as described in the first or second embodiment. Accordingly, the components similar to those of the first or second embodiment are shown in the figures with identical reference characters.

As shown in Figs. 7A and 7B, the present embodiment provides loop thermosyphon 100C with a condenser 130C similar to condensers 130A and 130B of loop thermosyphons 100A and 100B described in the first and second embodiments. More specifically, condenser 130C is unitized as an assembly formed of header pipe 131 associated with a feed pipe, header pipe 132 associated with a return pipe, the plurality of aligned pipes 133 connecting header pipes 131 and 132 together, and radiating fin 136 provided in contact with aligned pipes 133.

In the present embodiment condenser 130C is arranged to entirely incline by angle θ_1 to have aligned serpentine tube 133 with linear portions 134a-134d inclined to be closer to bottom surface 301 as the serpentine tube approaches header pipe 132. Furthermore condenser 130B is arranged to entirely incline by angle θ_2 such that header pipe 132 is inclined in a direction allowing header pipe 132 to have a smaller distance to bottom surface 301 for one end having return pipe 140 connected thereto than the other end located opposite to one end.

Thus the effect of the first embodiment and that of the second embodiment can both be achieved. This can significantly reduce a defective operation of the loop thermosyphon attributed to disposition. Thus the loop thermosyphon can reliably operate and the Stirling refrigerating machine can be operated highly efficiently.

Fourth Embodiment

The present embodiment provides a loop thermosyphon 100D also utilized as a heat transfer system associated with a heated portion of a Stirling refrigerating machine, similarly as described in the first to third embodiments. Accordingly, the components similar to those of the first to third embodiments are shown in the figures with identical reference characters.

As shown in Fig. 8, loop thermosyphon 100D has a condenser 130D with each aligned pipe 133 defined by linear portions 134a-134e linearly extending in a first direction (in the figure, direction A), and curved portions 135a-135d connecting linear portions 134a-134e. Linear portions 134a-134e are arranged, one on another, vertically in parallel. Curved portions 135a-135d connect linear portions 134a-134e at their respective ends together. More specifically, condenser 130D is configured of aligned pipes 133 configured of laterally arranged serpentine tubes. The plurality of aligned pipes 133 at linear portions 134a-134e have a plurality of radiating fins 136 assembled thereto.

Thus if a condenser formed of an assembly having an odd number of aligned pipes 133 each formed of a serpentine tube is employed, header pipe 131 associated with the feed pipe and header pipe 132 associated with the return pipe will separately be arranged at opposite ends of the condenser. Accordingly, in contrast to the first or third embodiment, condenser 130D needs to be arranged to incline to have its rear side to be closer to bottom surface 301. This allows aligned serpentine tubes 133 to have linear portions 134a-134e inclined in a direction allowing them to have a smaller distance to bottom surface 301 as they approach header pipe 132. Condenser 130D can be arranged to incline relative to bottom surface 301 of casing 300 for example by adjusting support 254C of support platform 250 in height (see Fig. 1).

Thus a condenser having aligned pipes 133 in an odd number of stages in layers that is entirely inclined relative to a bottom surface of a casing by angle θ_1 also allows a loop thermosyphon to reliably operate regardless of how the casing is disposed.

Fifth Embodiment

The present embodiment provides a loop thermosyphon 100E also utilized as a heat transfer system associated with a heated portion of a Stirling refrigerating machine, similarly as described in the first to fourth embodiments. Accordingly, the components similar to those of the first to fourth embodiments are shown in the figures with identical reference characters.

As shown in Fig. 10, loop thermosyphon 100E has a condenser 130E with aligned pipes 133 each defined by linear portions 134a-134c linearly extending in a first direction (in the figure, direction A) parallel to bottom surface 301 of casing 300 of equipment, linear portion 134d located at a bottommost stage and inclined relative to bottom surface 301, and curved portions 135a-135c connecting linear portions 134a-134d. Linear portions 134a-134d have their respective ends connected together by curved portions 135a-135c. The plurality of aligned pipes 133 at linear portions 134a-134d have a plurality of radiating fins 136 assembled thereto.

Condenser 130E has the bottommost linear portion 134d inclined in a direction allowing linear portion 134d to have a smaller distance to bottom surface 301 as linear portion 134d approaches header pipe 132. In other words, linear portion 134d is inclined relative to bottom surface 301 by an angle θ_3.

The working fluid flowing in condenser 130E through aligned pipe 133 is condensed and liquefied mainly at the bottommost linear portion 134d and pulled by gravity to flow through the inclined linear portion 134d toward header pipe 132 and flow out of aligned pipe 133. As such, aligned pipe 133 will not have the liquefied working fluid staying therein. The bottommost linear portion 134d previously alone inclined relative to bottom surface 301 of casing 300 by a prescribed angle allows the working fluid to smoothly flow regardless of how the casing is disposed, and loop thermosyphon 100E can reliably operate.

Sixth Embodiment

The present embodiment provides a loop thermosyphon 100F also utilized as a heat transfer system associated with a heated portion of a Stirling refrigerating machine,

similarly as described in the first to fifth embodiments. Accordingly, the components similar to those of the first to fifth embodiments are shown in the figures with identical reference characters.

As shown in Fig. 11, the present embodiment provides loop thermosyphon 100F having a condenser 130F with the plurality of aligned pipes 133 each defined by linearly extending portions 134a-134d and curved portions 135a-135c connecting linear portions 134a-134d together. Linear portions 134a-134d have their respective ends connected together by curved portions 135a-135c. The plurality of aligned pipes 133 at linear portions 134a-134d have a plurality of radiating fins 136 assembled thereto.

Condenser 130E has linear portions 134a-134d each arranged to incline in a direction allowing linear portions 134a-134d to have a smaller distance to bottom surface 301 of casing 300 of the equipment as the linear portions extend downstream (or extend from header pipe 131 toward header pipe 132). In particular, the bottommost linear portion 134d is inclined relative to bottom surface 301 by an angle θ_4.

The working fluid flowing in condenser 130E through aligned pipe 133 is condensed and liquefied mainly at the bottommost linear portion 134d. However, as the surrounding temperature or the like varies, aligned pipe 133 occasionally has the working fluid condensed and liquefied not only at the bottommost linear portion 134d but also linear portions 134a-134c overlying linear portion 134d. Linear portions 134a-134d each arranged to incline by a prescribed angle to allow the working fluid condensed and thus liquefied in linear portions 134a-134d to be pulled by gravity to return through the inclined linear portions 134a-134c toward header pipe 132, can prevent aligned pipe 133 from having the working fluid staying therein.

Linear portions 134a-134d thud previously arranged to incline relative to bottom surface 301 of casing 300 by a prescribed angle allows the working fluid to smoothly flow regardless of how casing 300 is disposed, and as a result allow loop thermosyphon 100F to reliably operate.

Seventh Embodiment

The present embodiment provides a loop thermosyphon 100G also utilized as a heat transfer system associated with a heated portion of a Stirling refrigerating machine, similarly as described in the first to sixth embodiments. Accordingly, the components similar to those of the first to sixth embodiments are shown in the figures with identical reference characters.

As shown in Fig. 12, the present embodiment provides loop thermosyphon 100G including a condenser 130G having header pipe 131 associated with a feed pipe and extending vertically, header pipe 132 associated with a return pipe and also extending vertically, and the plurality of aligned pipes 133 connecting header pipes 131 and 132 together. The plurality of aligned pipes 133 are each a linearly extending pipe and a plurality of such linear tubes are vertically arranged in parallel layers to form condenser 130G. The plurality of aligned pipes 133 has a plurality of radiating fins 136 assembled thereto. Note that in condenser 130G header pipe 131 extends in a direction orthogonal that in which each aligned pipe 133 extends and header pipe 132 extends in a direction orthogonal to that in which each aligned pipe 133 extends.

In the present embodiment loop thermosyphon 100G has condenser 130G arranged to entirely incline relative to bottom surface 301 of casing 300 of equipment by an angle θ_5 so that condenser 130G has aligned pipes 133 each arranged to incline in a direction allowing the aligned pipe to have a smaller distance to bottom surface 301 of casing 300 of the equipment as the aligned pipe extends downstream (or extends from header pipe 131 toward header pipe 132).

Condenser 130G previously, entirely inclined to allow the working fluid condensed and thus liquefied in aligned pipe 133 to be pulled by gravity to return through aligned pipe 133 toward header pipe 132, can prevent aligned pipe 133 from having the working fluid staying therein. The working fluid can smoothly flow regardless of how casing 300 is disposed, and as a result loop thermosyphon 100F can reliably be operated.

While the present embodiment has been described by exemplifying a condenser

with header pipes associated with feed and return pipes, respectively, arranged to vertically extend, the header pipes may be arranged to extend horizontally. If the header pipes are thus arranged, the header pipes will be connected by parallel or linear tubes arranged horizontally in parallel. In that case, the condenser is similarly arranged to entirely incline relative to a bottom surface of a casing of equipment by a prescribed angle so that the condenser has the aligned pipes each arranged to incline in a direction allowing the aligned pipe to have a smaller distance to the bottom surface as the aligned pipe extends downstream (or extends from the header pipe associated with the feed pipe toward that associated with the return pipe). The loop thermosyphon can reliably operate.

Furthermore, the header pipes associated with the feed and return pipes, respectively, may not be connected by aligned pipes arranged in a single row. For example the aligned pipes may be staggered in a direction traversing that in which the aligned pipes extend.

Eighth Embodiment

The present embodiment provides a loop thermosyphon 100H also utilized as a heat transfer system associated with a heated portion of a Stirling refrigerating machine, similarly as described in the first to seventh embodiments. Accordingly, the components similar to those of the first to seventh embodiments are shown in the figures with identical reference characters.

As shown in Fig. 13, the present embodiment provides loop thermosyphon 100H including a condenser 130H having header pipe 131 associated with a feed pipe and extending vertically, header pipe 132 associated with a return pipe and also extending vertically, and the plurality of aligned pipes 133 connecting header pipes 131 and 132 together. The plurality of aligned pipes 133 are each a linearly extending pipe and a plurality of such linear tubes are vertically arranged in parallel layers to form condenser 130H. The plurality of aligned pipes 133 has a plurality of radiating fins 136 assembled thereto. Note that for loop thermosyphon 100H header pipes 131 and 132 are

arranged such that header pipes 131 and 132 extend in a direction overlapping a normal to bottom surface 301 of casing 300 of equipment.

In the present embodiment loop thermosyphon 100H has linear aligned pipes 133 arranged to entirely incline relative to bottom surface 301 by an angle θ_6 so that condenser 130G has aligned pipes 133 each arranged to incline in a direction allowing the aligned pipe to have a smaller distance to bottom surface 301 as the aligned pipe extends downstream (or extends from header pipe 131 toward header pipe 132).

Aligned pipe 133 previously inclined to allow the working fluid condensed and thus liquefied therein to be pulled by gravity to return therethrough toward header pipe 132, can be prevented from having the working fluid staying therein. The working fluid can smoothly flow regardless of how casing 300 is disposed, and as a result loop thermosyphon 100G can reliably be operated.

While the present embodiment has been described by exemplifying a condenser with header pipes associated with feed and return pipes, respectively, arranged to vertically extend, the header pipes may be arranged to extend horizontally. If the header pipes are thus arranged, the header pipes will be connected by parallel, linear tubes arranged horizontally in parallel. In that case, the condenser is similarly arranged to entirely incline relative to a bottom surface of a casing of equipment by a prescribed angle so that the condenser has the aligned pipes each arranged to incline in a direction allowing the aligned pipe to have a smaller distance to the bottom surface as the aligned pipe extends downstream (or extends from the header pipe associated with the feed pipe toward that associated with the return pipe). The loop thermosyphon can reliably operate.

Furthermore, the header pipes associated with the feed and return pipes, respectively, may not be connected by aligned pipes arranged in a single row. For example the aligned pipes may be staggered in a direction traversing that in which the aligned pipes extend.

Ninth Embodiment

The present embodiment provides a Stirling refrigerator having the loop thermosyphon of any of the first to eighth embodiments as a heat transfer system associated with a heated portion of a Stirling refrigerating machine disposed in a casing.

As shown in Fig. 14, the present embodiment provides a Stirling refrigerator 1000 including a freezer section 1028 and a chiller section 1029 as a refrigeration section. Stirling refrigerator 1000 includes loop thermosyphon 100 as a heat transfer system associated with a heated portion to cool a heated portion 204 of a Stirling refrigerating machine 200. Stirling refrigerating machine 200 has a cold portion 206 generating cryogenic temperature utilized by a heat transfer system 1020 associated with the cold portion (indicated in Fig. 14 by a broken line) to cool the refrigerator's interior. As well as the heat transfer system associated with the heated portion, the heat transfer system associated with the cold portion may also be configured of a loop thermosyphon or may be a heat transfer system utilizing forced convection.

The heat transfer system associated with the heated portion, or loop thermosyphon 100, includes evaporator 110 attached to surround and thus contact heated portion 204 of Stirling refrigerating machine 200, and condenser 130 connected to evaporator 110 by a feed pipe and a return pipe. Evaporator 110, condenser 130 and feed and return pipes 120 and 140 form a circulation circuit having ethanol-added water or the like sealed therein as a coolant. To allow the coolant's evaporation and condensation and resultant natural circulation to be utilized to transfer heat generated at heated portion 204, condenser 130 is arranged to be upper (or higher) than evaporator 110.

As shown in Fig. 14, Stirling refrigerating machine 200 is arranged in Stirling refrigerator 1000 at a rear, upper portion. Furthermore, heat transfer system 1020 associated with the cold portion is arranged in Stirling refrigerator 1000 closer to the rear side. In contrast, the heat transfer system associated with the heated portion, or loop thermosyphon 100, is arranged in Stirling refrigerator 1000 at an upper portion. Note that thermosyphon 100 has condenser 130 provided in a duct 1024 provided in

Stirling refrigerator 1000 at an upper portion.

When Stirling refrigerating machine 200 is operated, heated portion 204 generates heat, which is thermally exchanged via condenser 130 of thermosyphon 100 with air present in duct 1024. An air blowing fan 1025 exhausts warm air present in duct 1024 to outside Stirling refrigerator 100 and also introduces air external to Stirling refrigerator 1000 to help to exchange heat.

In contrast, cold portion 206 generates cryogenic temperature, which is thermally exchanged with an air stream present in cold duct 1023, as indicated in Fig. 14 by an arrow. A fan 1026 associated with a freezer section and a fan 1027 associated with a chiller section blow cooled, cold air toward freezer section 1028 and chiller section 1029, respectively. Each refrigeration section 1028, 1029 provides a warm air stream which is again introduced into cold duct 1023 and repeatedly cooled.

As loop thermosyphon 100 mounted in Stirling refrigerator 1000 as described above is any of loop thermosyphons 100A-100H described in the first to eighth embodiments, it can reliably operate regardless of how Stirling refrigerator 100 has a casing disposed. Stirling refrigerating machine 200 can be operated significantly efficiently and Stirling refrigerator 1000 can also be improved in performance.

Tenth Embodiment

The present embodiment provides a cooling apparatus having a major portion common in structure to that of the second conventional example described hereinbefore. Accordingly, components identical to those of the cooling apparatus of the second conventional example are identically labeled.

As shown in Figs. 15, and 16A and 16B, the present embodiment provides a cooling apparatus having condensate coolant pipe 11 having vertical pipes 11A and 11B with their respective upper ends connected to a lateral pipe 11C at one and the other ends, respectively, and their respective lower ends connected to semi-rings 6A and 6B at their respective outer circumferential upper ends, respectively, similarly as has been done in the second conventional example. Thus vertical pipes 11A and 11B are connected at

upper and lower ports that do not match as seen horizontally. Accordingly, vertical pipes 11A and 11B are implemented by bent pipes having inclined portions 11Aa and 11Ba having a downward gradient (see Fig. 16A). If cooling apparatus 50 (see Fig. 20) more or less inclines, lateral pipe 11C will have one of the ends lowest in level of the entirety of lateral pipe 11C. The coolant's condensate will flow through the vertical pipe having a lower inlet and thus be prevented from staying in lateral pipe 11C.

In general, refrigerators are to be installed at places having an inclination of at most 5° including no inclination. Accordingly by setting at least 5° for a downward gradient α of inclined portions 11Aa and 11Ba of the vertical pipes with reference to cooling apparatus 500 placed with no inclination (see Fig. 16A), the vertical pipes can have inclined portions 11Aa and 11Ba with the downward gradient maintained if cooling apparatus 50 is inclined by 5°, and the thermosyphon can be prevented from failing to function. Thus the coolant can reliably be circulated.

Furthermore, vapor coolant pipe 11 has lateral pipe 11C with a degassing charge pipe 21 attached thereto. If the heat transfer cycle associated with the heated portion is operated with water used as a coolant, an uncondensed gas (or air) solved and thus present in water needs to be removed. Accordingly, after the water or coolant is shielded charge pipe 21 is used to vacuum a shielded system internal to the cycle. Charge pipe 21 attached at a location high in level can prevent water from being sucked in vacuuming the shielded system and can also improve efficiency in vacuuming the system.

The first to tenth embodiments have been described by exemplifying a loop thermosyphon employed in a heat transfer system associated with a heated portion of a Stirling refrigerating machine, the present invention is as a matter of course also applicable to other devices having a heat source.

Furthermore, characteristic configurations described in the first to tenth embodiments can be combined together.

The above disclosed embodiments are by way of illustration and example only

and are not to be taken by way of limitation, the spirit and scope of the present invention being limited only by the terms of the appended claims and encompassing any variation falling within a meaning and scope equivalent to the claims.